# CHAPTER 2

## ELECTRICAL CLASSIFICATION OF MATERIALS

Electrons are contained in sub-shells within major shells, as they orbit around the nucleus. In general, the electrical properties o. a material are determined by —

(a) the distance the outer main shell of the atoms in the material is from the nucleus.

(b) the number of the sub-shell in which the valence electrons exist.

(c) the number of electrons in the valence sub-shell.

As stated previously, valence band electrons may be removed from the influence of their nuclei. The classification of materials depends mainly on the ease or difficulty associated with the shifting of these valence electrons.

### 2.1 CLASSIFICATION OF MATERIALS

The three electrical classifications of materials are —

(a) conductor
(b) semiconductor
(c) insulator

The classification of a material is made on the assumption that the material is operating under normal conditions, as some materials have completely different characteristics if these conditions are altered. Normal conditions exist at atmospheric pressure and temperature.

(a) Conductor

Elements whose electrons are easily removed from their orbits are termed conductors. The conductor has its atoms held together by a metallic bond. This bond occurs when there is a continuous interchange of electrons between adjacent atoms. The electrical conductor is normally a solid material having one electron in the first sub-shell of the outer major shell. Typical of these are gold, silver and copper. Gold has one electron in the first sub-shell of the 'P' shell. There are no electrons in the forth and fifth sub-shells of the 'O' shell. (Figure 2.1).

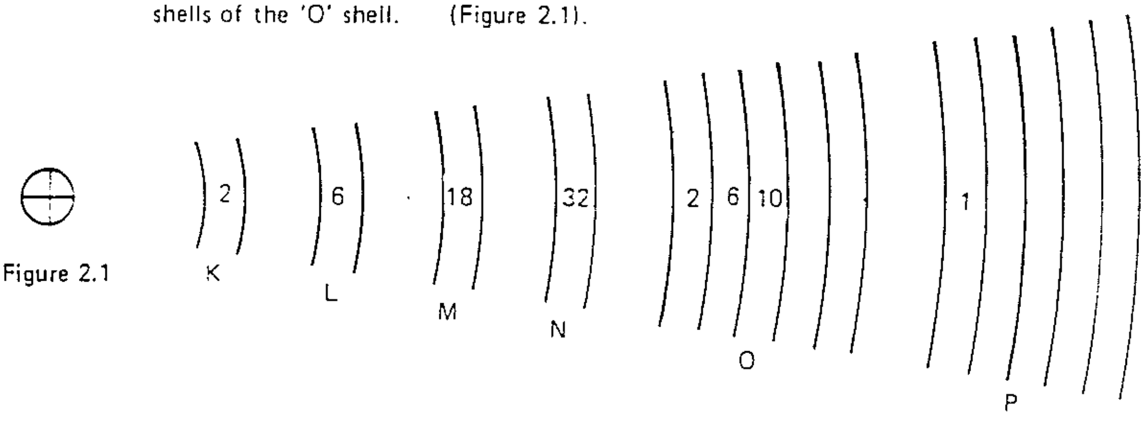



Figure 2.1

The one electron in the 'P' shell is loosely bound to the nucleus because of the large electron free gap between it and the third sub-shell of the 'O' shell. For this reason it is easily removed from its orbit, thus making gold a good conductor of electricity.

Silver has one electron in the first sub-shell of the 'O' shell, separated from the third sub-shell of the 'N' shell by one empty sub-shell and a forbidden band. (Figure 2.2).

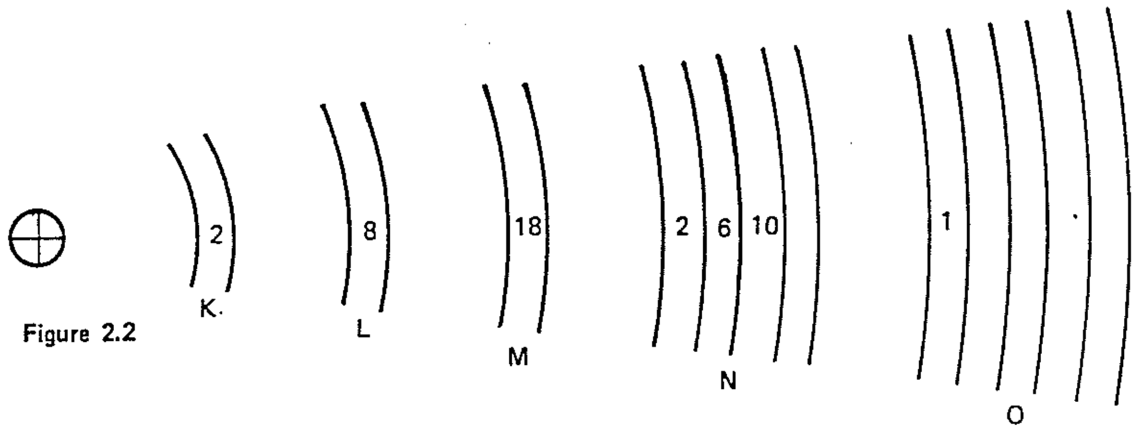


Figure 2.2

Similarly copper has one electron in the first sub-shell of the 'N' shell. This electron is more tightly bound to the nucleus than the single electron of silver or gold but is still separated from the next shell by a forbidden band and shifts readily.

Other factors besides the three mentioned earlier in this chapter influence the ability of electrons to shift from one energy level to another energy level. When all these factors are taken into account, the best solid conductors are silver, gold and copper in that order. Copper is the most extensively used however, because of its relatively low cost compared with the cost of silver and gold.

Although it has three electrons in its outer shell and is not as good a conductor as copper, aluminium is being increasingly used as the conductor in electrical cable. The reason for this is that when compared with copper, aluminium is far lighter and less expensive.

(b) **Semiconductors**

The outer major shell of simiconductor materials has the first sub-shell filled with its two electrons and two electrons in the second sub-shell. Typical semiconductor materials are silicon and germanium. (Figure 2.3).

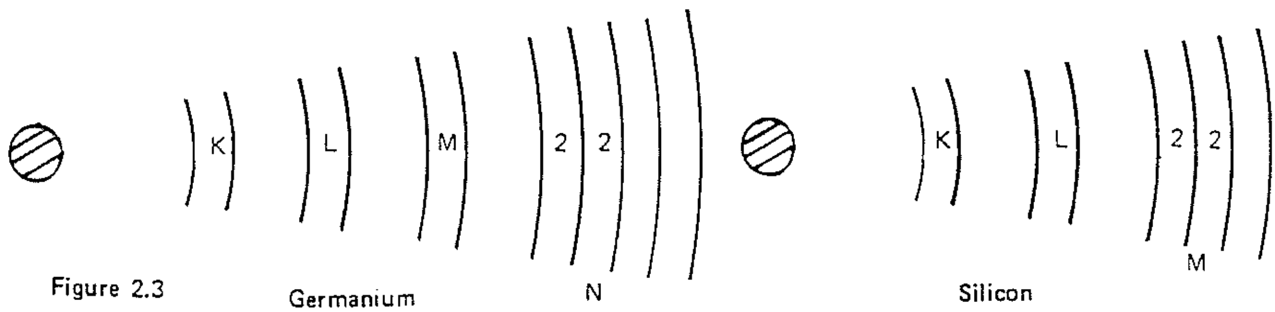
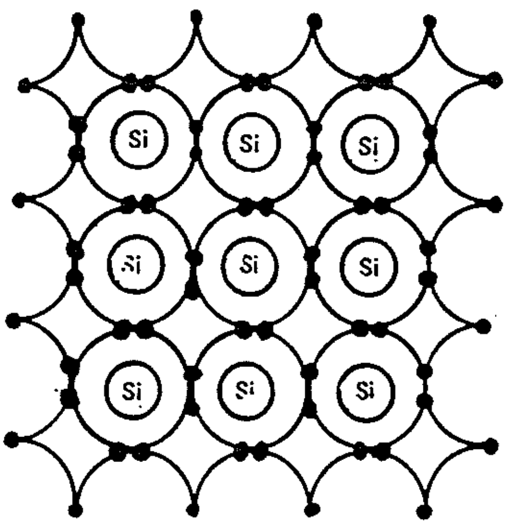


Figure 2.3

Because the semiconductor material has four electrons in the outer main shell it is said to have a valency of four. Four adjacent atoms in semiconductor material share the two electrons in the outer sub-shell to complete the maximum number of eight electrons allowable in a second main shell. This is known as covalent bonding. (Figure 2.4).

Figure 2.4




Only the electrons in the second sub-shell are shown in Figure 2.4 as these are the electrons that determine the electrical properties of the material. Electrons will move at random through semiconductor material at room temperature, but not in the same numbers as in conductor materials.

(c) **Insulators**

Insulators are materials in which it is very difficult to shift electrons from their valence band. They usually have one or two electrons less than the maximum number allowable in the second or third sub-shell. Few natural elements are used as insulators, most commercial insulators being a compound of two or more elements. Typical insulators are rubber, plastics, glass, mica and ceramics.

The classification of different materials is related to their ability to allow the passage of electrical current. Conductor materials offers the least amount of opposition to the movement of electrons. Insulator material opposes electron movement. The uses of semi-conductor material is discussed in latter chapters.

## 2.2 DOPING OF SEMICONDUCTOR MATERIALS

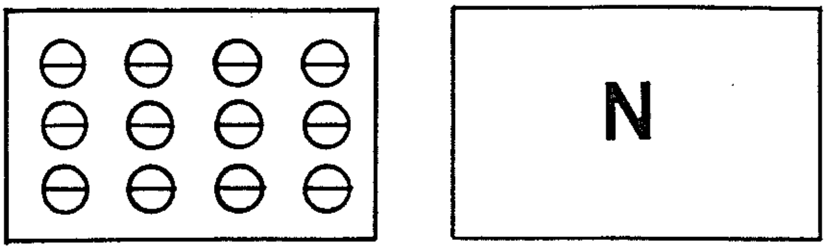
Semiconductor material has a cubic or crystalline lattice structure. Like all materials composed of complete atoms, it is electrostatically neutral. Atoms which have a valency of three or five may be introduced into the semiconductor material while it is in the molten state. Because of the low number of atoms mixed into the pure semiconductor material, these atoms are known as impurity atoms. The introduction of these impurity atoms into the pure semiconductor material is called doping of that material. Doping of semiconductor material may form either p or n type semiconductor material depending on the valency of the impurity atoms used. The ratio of impurity atoms to pure semi-conductor atoms is approximately one in ten million.

### n TYPE MATERIAL

Atoms of elements such as phosphorus and arsenic have a valency of five. The outer main shell of these atoms has its first sub-shell complete with its two electrons while its second sub-shell contains three electrons. If one of these atoms is combined with pure semiconductor atoms, two of the electrons in the impurity atom will combine with electrons in the semiconductor atoms to fill the second sub-shell. This will leave one electron unbonded, or free, from the lattice structure. This electron moves at random throughout the semiconductor material much like the electron in conductor materials. However, because of the small number of impurities in the semiconductor material there will not be as many free electrons in the doped material as in a conductor.

As the only change in the cubic structure of the doped material is the unbonded electron (negative charge), this type of material is called n type semiconductor material and its existance is as indicated in Figure 2.5.

Figure 2.5

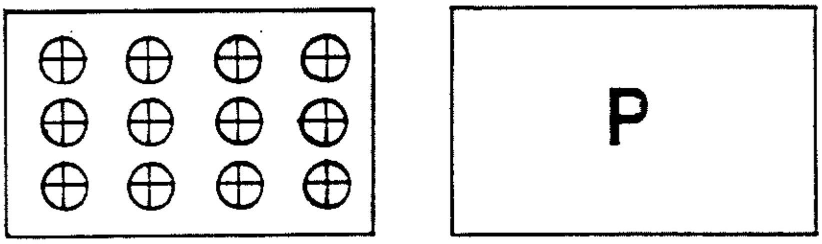



n type material is made by combining neutral atoms of semiconductor material with neutral atoms of impurity elements, so the n type material itself must also be neutral, or exhibit no charge.

## p TYPE MATERIAL

Elements such as galium and indium have a valency of three. Their outer main shell has its first sub-shell complete with its two electrons, but the second sub-shell has only one electron. When an impurity atom with a valency of three is inserted into the pure semiconductor material, the one electron in its outer sub-shell is not sufficient to complete the lattice structure. Instead of all atoms having eight shared electrons in the outer sub-shell, the impurity atom has only seven, thus creating a gap or hole in the structure. This hole will attract any stray electron which may be in the vicinity of the impurity atom Because of this attraction for an electron ( – ) the existance of this type of doped semiconductor material is shown by a plus ( + ) sign, or the letter **p**. (Figure 2.6).

Figure 2.6



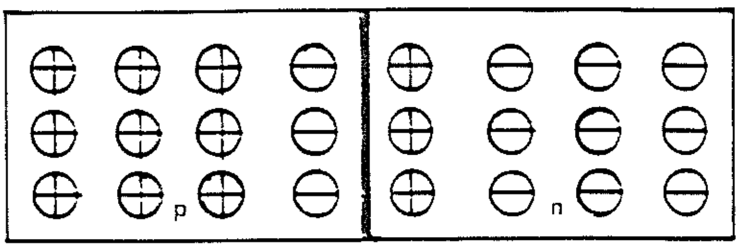

Again, as only neutral atoms are involved in changing the semiconductor material, the doped material must be neutral.

## 2.3 THE pn JUNCTION

As stated, both the n and p type materials are neutral in charge, although the n type has unbonded electrons, and the p type holes which will attract electrons.

If a piece of each material is joined together, there will be an electrostatic change at the joint or junction of the materials. Unbonded electrons in the n type material will move across the junction into holes in the p type material. These electrons can only move a certain distance into the p type material because they are still held by the attractive forces of their parent nuclei. The movement of the electrons from the neutral n impurity atom, ionises that atom, making it exhibit positive charge. The gaining of an electron to fill a hole in a neutral p impurity atom causes the impurity to ionise and exhibit negative charge. There is said to be a depletion of charges at the junction. (Figure 2.7).

Figure 2.7



As there has only been a sharing, not a loss or gain, of electrons, when the neutral **n** and **p** materials combine, the **pn** junction itself must be neutral in charge. The impurity atom in the **n** type material is called a donor atom, as it gives its electrons to the impurity atom in the **p** type material, which is known as the acceptor atom.

The joining or fusing together of **p** and **n** type material is used extensively in the electronic field, specific applications being discussed in Stage 2.

## TUTORIALS 1.2

More difficult transposition

(1) Make $r_1$ the subject in $R = \dfrac{1}{\dfrac{1}{r_1} + \dfrac{1}{r_2}}$

(2) Make I the subject in $P = I^2R$

(3) Make L the subject in $Z = 2 \pi f L$

(4) Make $E_R$ the subject in $E = \sqrt{E_R^2 + (E_c - E_L)^2}$

(5) Make C the subject in $X = \dfrac{10^6}{2 \pi f C}$

(6) Make I the subject in $P = \sqrt{3}\, E\, I \cos \phi$

(7) Make P the subject in $E = \dfrac{\Phi ZPN}{60C}$

(8) Make E the subject in $R\% = \dfrac{E - V}{V} \times \dfrac{100}{1}$

(9) Make R the subject in $Z = \sqrt{R^2 + X^2}$

(10) Make $\Phi$ the subject in $E = 4.44\, \Phi\, f\, t$